Improved Liquid-Cooled Inductive Devices with Interspersed Winding Layers and Directed Coolant Flow

Field of the Invention

The invention relates to liquid-cooled inductive devices, and more particularly to high-power liquid-cooled inductive devices with multi-layer windings.

Cross Reference to Related Applications

This Application claims the benefit of the filing date for prior filed co-pending Provisional Application Serial Number 60/458,788, filed 28 March 2003.

Background of the Invention

When high power inductive devices, such as inductors and transformers, are implemented, it is common to bathe such devices in a liquid coolant such as oil to more effectively remove heat generated by losses in the devices. When such devices have multi-layer windings, the innermost layer or layers tend to exhibit significantly higher temperature than the outer layer or layers. This temperature differential causes premature failure of the devices.

Summary of the Invention

A liquid-cooled device with at least one multi-layer winding, such as an inductor or transformer, is wound so that at least a few turns of the outer layer or layers of the multi-layer winding are embedded or interspersed with the inner layer or layers. This directly exposes the inner layer or layers to the coolant and increases the heat transfer to the coolant, thereby lowering the temperature of the inner layer. Furthermore, a coolant flow diverter is used to force coolant within the region of the interspersed winding layers that form a gap in the outer winding layer or layers of the multi-layer winding.

Description of the Drawings

Figure 1 shows a top view of an oil diverter according to the invention.

Figure 2 shows a bottom view of an oil diverter according to the invention.

Figure 3 shows the cover side of a housing for an inductive device according to the invention, minus its cover.

Figure 4 shows the housing of Figure 3 with its cover, opposite its cover side.

Figure 5 shows how inner and outer winding layers of a coil for an inductive device according to the invention are interspersed.

Figure 6 shows the completed inductive device coil for an inductive device according to the invention.

Figure 7 shows two of the completed inductive device coils of Figure 6 assembled on a core for an inductive device according to the invention.

Figure 8 shows a side view of the impregnated core with coils for an inductive device according to the invention.

Figure 9 shows the coil configuration for an inductive device according to the prior art without interspersed winding layers.

Figure 10 shows the assembly of an inductive device according to the prior art without directed coolant flow.

Description of the Embodiment

Figures 9 and 10 show a prior art high-power, liquid-cooled inductive device 2, in this case, a transformer of the inter-phase type that is used to join two three-phase full wave rectified diode bridges to create twelve pulse rectification in aerospace applications. The inductive device 2 has a core-coil assembly 4 with an inductive device core 6 and two multi-layer windings 8. In this case, each multi-layer winding 8 comprises an inner layer (not shown) and an outer layer 10, so no coolant is expected to come directly in contact with the inner layer of each multi-layer winding 8.

Figure 10 shows that the inductive device 2 lacks any sort of directed coolant flow within the inductive device 2. A spacer 12, shown at the bottom of Figure 10, fits within the inductive device 2. It serves only to locate the inductive device core 4 with its multi-layer windings 8 in place within a housing 14, shown on the right side of Figure 10, prior to placing a housing cover 16, shown on the left side of Figure 10, on the housing 14 to seal the inductive device 2.

Shown in Figures 1 through 8 are how a high-power, liquid-cooled inductive device, in this case, a prior art inductive device 2 such as shown in Figures 9 and 10, may be adapted to incorporate the interspersed multi-layer winding and the directed coolant flow features according to the invention. Although an inter-phase transformer is described as a specific embodiment, those skilled in the art shall recognise that this invention may be incorporated in any high-power, liquid-cooled inductive device.

The primary purpose of the invention is to direct coolant, in this case oil, over all the winding layers of the inductive device 2 such that the heat transfer, especially of the inner layer of each multi-layer winding 8, is increased. To that end, a few turns of the outer layer 10 of each multi-layer winding 8 are embedded or interspersed between those of the inner layer, as shown in Figure 5, to create an interspersed central section 18 that forms a gap between the ends of the outer layer 10 in the multi-layer winding 8, as shown in Figure 6. The multi-layer windings 8 are then mounted on the inductive device core 6 to form the coil-core assembly 4, as shown in Figure 7, and then the coil-core assembly 4 is impregnated, as shown in Figure 8.

A flow diverter 20 according to the invention is shown in Figures 1 and 2. The flow diverter 20 is sized with tight tolerances so that the vast majority of the coolant is forced between the top of the housing 14 and the flow diverter 20 itself. The flow diverter 20 is machined from a suitable high-temperature material with good electrical insulation properties, such as polyamide-imide plastic, commonly known as Torlon ®. Referring to Figures 1 and 3 together, the flow diverter 20 is formed to sit in the housing 14 such that a ramp 22 interfaces a coolant inlet port 24 of the housing 14 with an inlet channel 26 that leads to a plurality of holes that penetrate through the flow diverter 20, such as the

three holes 28 shown in Figures 1 and 2. The holes 28 serve to force the coolant down through the interspersed central sections 18 of the multi-layer windings 8.

The flow diverter 20 is also machined with a large cut-out 30, as shown in Figure 2, that serves to seat the core-coil assembly 4 and direct the coolant to circulate around the core-coil assembly. The flow diverter 20 also has a flat 32 cut into its side that is aligned to couple with an outlet port 34 in the housing 14. The flat 32 serves as an outlet channel that allows coolant that circulates around the core-coil assembly 4 to exit from the outlet port 34. Preferably, the housing 14 has an interior tab 36 that mates with the flat 32 and provides an anti-rotation feature that keeps the flow diverter 20 and core-coil assembly 4 in alignment within the housing 14.

Although an inter-phase transformer is described as a specific embodiment, those skilled in the art shall recognise that this invention may be incorporated in any high-power, liquid-cooled inductive device. In particular, the multi-layer winding 8 may have more than two layers, wherein the several layers are embedded or interspersed in the interspersed central section 18 to similarly form a gap between the ends of the outer layer 10, thus providing superior cooling of the inner layers in a similar fashion. Furthermore, the core-coil assembly 4 may include one or more multi-layer windings 8 so that any high-power inductive device may use this invention.

Thus there has been described herein a high-power, liquid-cooled, multi-layer winding inductive device that has a region of interspersed winding layers and directed coolant flow over the interspersed windings to improve heat transfer and device life. It should be understood that the embodiment described above is only one illustrative implementation of the invention and that the various parts and arrangement thereof may be changed or substituted.